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ANALYSIS OF TENSILE STRENGTH IN A COMBINATION OF RECYCLED HDPE PLASTIC AND LIQUID ASPHALT

Achmad Bryan Baharrudin Sofan [1], Moh. Hartono [1)*]

1) Mechanical Engineering Departement, Politeknik Negeri Malang, Jl Soekarno-Hatta 9, Malang, Indonesia

Correponding email [1] :
moh.hartono@polinema.ac.id

***Abstract*.** Plastic waste reuse has gained significant attention due to its potential to reduce environmental pollution and provide alternative materials for engineering applications, particularly in the construction sector where durability and maintenance issues are common. One persistent problem in building structures is roof leakage caused by long-term exposure to rainfall, ultraviolet radiation, and extreme temperature changes, which gradually damage conventional waterproofing materials. To improve performance, materials with higher tensile strength and flexibility are needed. High-Density Polyethylene (HDPE), a thermoplastic known for its strength and durability, offers promising reinforcement when combined with liquid asphalt, while also supporting environmentally sustainable practices by reducing plastic waste. In this study, liquid asphalt was heated to 40°C and mixed with HDPE heated at 200°C, 210°C, and 220°C, then stirred for 1.5 hours until homogeneous, cooled to room temperature, and molded according to ASTM D638 for tensile testing. The results show that the 90:10 (HDPE: asphalt) composition at 200°C produced the highest tensile strength of 6.14 MPa, while the 80:20 composition at 220°C showed the lowest value of 3.86 MPa, indicating that higher HDPE content at optimal melting temperatures enhances mechanical properties and provides strong potential for use as a durable, environmentally friendly waterproofing layer in building construction.

Keywords : Liquid Asphalt, Recycle HDPE, Tensile test.

1. INTRODUCTION

Plastic, a petroleum-derived material [1], is widely used in various aspects of daily life, ranging from packaging products to industrial components, and as a result, the global plastic waste crisis continues to worsen. Data shows that in 2022, global plastic production reached 400.3 million tons, with most of it ending up as waste that is difficult to decompose in the environment [2]. Managing plastic waste, particularly from domestic and industrial sectors, remains a significant unresolved challenge. HDPE that is not properly recycled can persist in the environment for hundreds of years, causing ecosystem disruption, soil contamination, and potential health risks to humans [3]. Several approaches have been explored to reduce plastic waste, one of which is the incorporation of recycled HDPE into asphalt mixtures as a means to improve material performance while supporting environmental sustainability.

Research has shown that adding HDPE to 60/70 penetration asphalt can enhance several physical properties, including penetration, softening point, specific gravity, and viscosity, while simultaneously reducing ductility, indicating that the presence of HDPE alters the mechanical behavior of the asphalt binder [4]. Further studies also highlight that HDPE-blended asphalt exhibits higher stiffness compared to conventional mixtures, as reflected by the increase in stability values from 1729.31 kg in mixtures without HDPE to 1776.77 kg, 1797.07 kg, and 1840.90 kg in mixtures containing 12%, 14%, and 16% HDPE, respectively [5]. In addition, HDPE-modified asphalt demonstrates increased density due to reduced pore size and a higher softening point, making the mixture more resistant to high temperatures and environmental conditions. The decrease in penetration values with the addition of HDPE indicates a stiffer binder, which can improve structural performance, although mixtures containing 6% HDPE do not meet the penetration requirements for modified asphalt [6].

However, the majority of these studies focus on road pavement applications, and there are still very few that evaluate HDPE as a mixture for coating materials in buildings, such as roofs or protective surfaces. Meanwhile, roof damage due to rainwater is common, such as holes around loose, rusted, or widened nails, allowing water to seep in and damage the building structure below [7]. To address this issue, this study developed a new material based on a mixture of liquid asphalt and High-Density Polyethylene (HDPE) plastic. Liquid asphalt, which is asphalt melted with a solvent from petroleum refining [8], is known for its waterproof properties and is commonly used as a roof coating. HDPE was chosen for its good mechanical properties and its ability to enhance the stiffness and waterproofing properties of the asphalt mixture [5]. Additionally, the temperature of HDPE plastic is 180–230 °C [9]. This study aims to produce a new material and explore the potential use of HDPE as a coating material.

To produce new material that is homogeneous and has optimal tensile properties, a proper mixing process is required. One method commonly used in mixing plastic and asphalt is the hot-hot mix method, which involves mixing plastic and asphalt while both are in a molten state [10]. This method is believed to produce better molecular integration than the cold method.

This study aims to examine the effect of HDPE temperature and mixture composition on the tensile strength of the material, using the ASTM D638 standard tensile test, which is widely used for testing plastic-based materials [11]. With this approach, it is hoped that new materials can be developed that are not only strong and durable but also environmentally friendly through the use of recycled plastic waste. Therefore, further research is still needed to understand how variations in temperature and mixture composition can affect mechanical properties, particularly tensile strength. This testing aims to determine how much the material can stretch without suffering permanent damage. Additionally, this research aims to contribute ideas for the utilization of plastic waste as an alternative for recycling.

2. METHODS

Figure 1 illustrates the research framework that follows. The research was conducted experimentally at the Material Testing Laboratory of the State Polytechnic of Malang from April to July 2025. The treatment variations consisted of three HDPE temperatures, namely 200 °C, 210 °C, and 220 °C, as well as three HDPE: liquid asphalt mixture compositions, namely 80:20, 85:15, and 90:10. The research was limited to HDPE recycled plastic pellets and MC 30 liquid asphalt. The plastic mixing method uses a method in which hot asphalt meets hot plastic. Tensile test was used to evaluate the mechanical properties of the mixture.

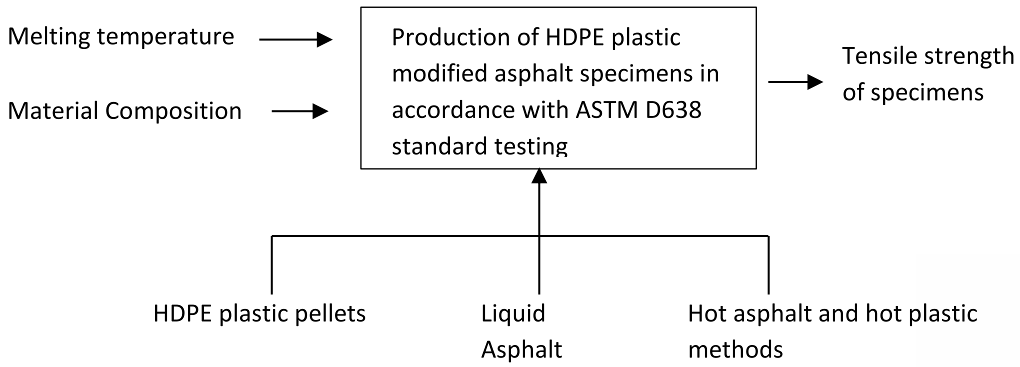

Figure 1. Research concept framework

The specimen production process begins with the selection of recycled HDPE plastic pellets as the main material to be mixed with MC 30 liquid asphalt. The first step involves calculating the mold volume based on the standard ASTM D638 mold dimensions to determine the amount of material required for each composition variation, such as 80:20, 85:15, and 90:10 (HDPE: liquid asphalt). After the mass of each material is obtained from the calculation of volume fraction and density, the heating process is carried out separately for both materials. Recycled HDPE plastic was heated in a pan until it reached its point at 200°C, 210°C, or 220°C depending on the treatment variation, while MC 30 liquid asphalt was heated in a separate container until it reached 40°C to remain in a liquid state. The mixing method used in this study is the hot asphalt–hot plastic mixture method, where both materials are first heated separately until they reach a liquid state, then mixed in a single container while both are still hot [13]. This method (Figure 2) is considered the most effective as it produces better molecular mixing and avoids the formation of lumps due to temperature differences. After the liquid asphalt was poured into the melted HDPE, the mixture was manually stirred using a metal spatula for 15–30 minutes until homogeneous, indicated by a uniform dark brown color change. The hot mixture is then poured into a metal mold, allowed to cool and harden at room temperature, then the specimen is removed from the mold and cut using a band saw to meet the ASTM D638 tensile test standard.

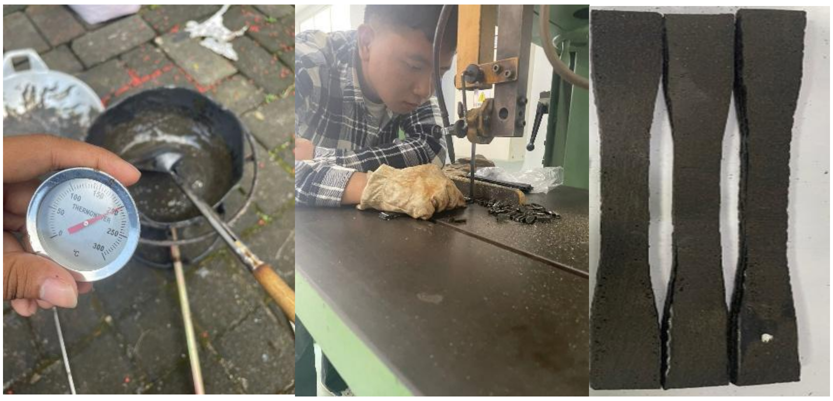

Figure 2. Specimen manufacture

In this study, tensile testing was used to test the strength of a material under axial force. Tensile testing was carried out by continuously pulling the test specimen with tensile force, so that the material (its elongation) continued to increase steadily until it broke, with the aim of determining the tensile value [11]. The testing standard used in this study is ASTM D638, which is a specific tensile test method for plastic-based materials [13]. This standard was chosen based on its suitability for the characteristics of the material used, namely a mixture of HDPE plastic and liquid asphalt, where mechanical properties such as tensile strength and maximum strain are the main parameters observed. Figure 3 shows an image of the tensile test specimen using the ASTM D638 standard. The standard sizes are shown in Table 1.

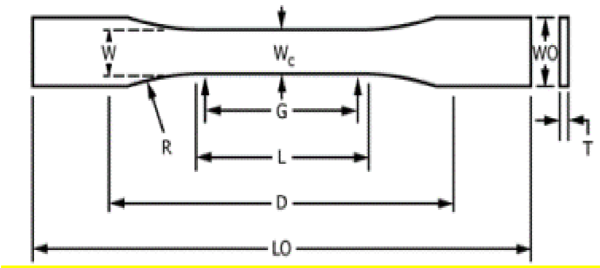

Figure 3. Spesimen ASTM D638

Table 1. Description Spesimen ASTM D638

No ID	Description	Dimension (mm)
1	Total length (L0)	165
2	Distance between grips (D)	115
3	Length of parallel section (L)	57
4	Gauge Length (G)	50
5	Radius (R)	76
6	Parallel section width	13
7	Total width (W0)	19
8	Thickness	4

3. RESULTS AND DISCUSSION

The tensile test data was processed with three replications to ensure the accuracy of the test data. Table 2 shows the tensile test results. Based on the test results, the tensile strength of each variation of point temperature at 200°C, 210°C, and 220°C and the composition of the mixture of the two materials between recycled HDPE plastic and liquid asphalt was obtained.

Table 2. Tensile Test Data

No	Temperature (°C)	Composition HDPE:Asphalt (%)	Pull Force (kg)	Pull Force(N)	Elongation (mm)	Tensile Test(MPa)	Strain (%)
1	200	80:20	23.6	231.28	7.82	4.81	0.16
2	200	80:20	22.4	219.52	9.96	4.56	0.2
3	200	80:20	21.6	211.68	6.22	4.40	0.12
4	200	85:15	26.2	256.76	6.84	5.34	0.14
5	200	85:15	28.4	278.32	6.31	5.79	0.13
6	200	85:15	32.6	319.48	3.47	6.64	0.07
7	200	90:10	29.6	290.08	4.71	6.03	0.09
8	200	90:10	27.2	266.56	4.27	5.54	0.09
9	200	90:10	33.6	329.28	5.51	6.85	0.11
10	210	80:20	22.4	219.52	6.84	4.56	0.13
11	210	80:20	18.2	178.36	8.18	3.71	0.16
12	210	80:20	21.2	207.76	2.48	4.32	0.04
13	210	85:15	28.6	280.28	4.97	5.83	0.11
14	210	85:15	22.2	217.56	6.22	4.52	0.12
15	210	85:15	20.2	197.96	5.77	4.12	0.12
16	210	90:10	25.4	248.92	12.26	5.18	0.24
17	210	90:10	31.4	307.72	8.98	6.40	0.17
18	210	90:10	29.2	286.16	16.79	5.95	0.33
19	220	80:20	16.4	160.72	3.47	3.34	0.06
20	220	80:20	19.8	194.04	2.84	4.03	0.05
21	220	80:20	20.6	201.88	4.00	4.20	0.08
22	220	85:15	22.8	223.44	8.98	4.65	0.17
23	220	85:15	23.8	233.24	2.22	4.85	0.04
24	220	85:15	22.4	219.52	6.22	4.56	0.12
25	220	90:10	27.6	270.48	6.84	5.62	0.13
26	220	90:10	27.8	272.44	5.15	5.66	0.1
27	220	90:10	28.4	278.32	8.18	5.79	0.15

The maximum tensile load is the highest force value achieved by the specimen before failure or breakage. Then, the maximum tensile strength is calculated by dividing the maximum load by the cross-sectional area of the test specimen. This value represents the maximum stress that the material can withstand before permanent deformation or failure occurs, as shown in Table 3.

Table 3. Maximum Tensile Strength Data

Temperature (°C)	HDPE composition: Asphalt (%)	Tensile Strength (MPa)			Average Tensile Strength (Mpa)
		Test 1	Test 2	Test 3	
200 C	80:20	4.81	4.56	4.40	4.59
210 C		5.38	3.71	4.32	4.47
220 C		3.34	4.03	4.20	3.86
200 C	85:15	5.42	5.79	6.64	5.95
210 C		5.83	4.52	4.12	4.82
220 C		4.65	4.85	4.56	4.69
200 C	90:10	6.03	5.54	6.85	6.14
210 C		5.18	6.40	5.95	5.84
220 C		5.62	5.66	5.79	5.69

Figure 4 shows a diagram of the relationship between tensile stress and strain of specimens made from a mixture of recycled HDPE plastic and liquid asphalt with a composition ratio of 80/20 at melting temperatures of 200°C, 210°C, and 220°C. This graph provides an overview of the mechanical characteristics of each specimen in relation to the plastic deformation that occurred during the tensile test. Based on Figure 4, the relationship between stress and strain in the recycled HDPE and liquid asphalt mixture with a composition of 80/20 shows differences in behavior at each variation in temperature. At 200 °C, stress increases steadily until reaching a maximum value of 4.8 MPa at a strain of 0.1564%, indicating that the material has good strength and flexibility. At 210 °C, stress increases and then suddenly decreases, with a lower strain compared to 200 °C. Meanwhile, at 220 °C, the stress tends to be low, and the graph flattens out after a certain point. This indicates that an increase in melting temperature affects the reduction in the material's mechanical performance, and 200 °C is the most optimal condition within this testing range.

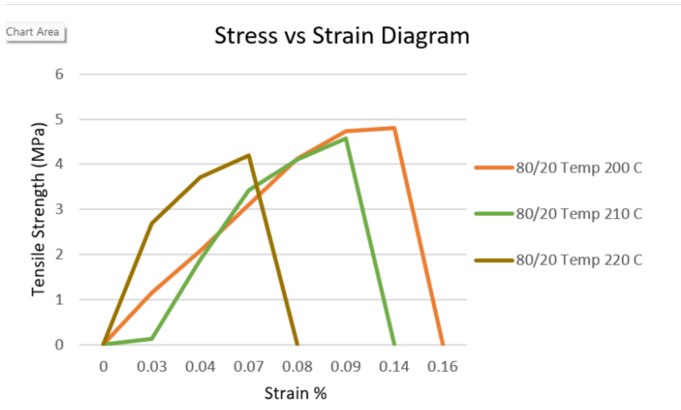

Figure 4. Stress-strain graph of 80/20 composition

Figure 5 shows a graph of the relationship between tensile stress and strain in specimens composed of 85% recycled HDPE plastic and 15% liquid asphalt, tested at three different melting temperatures: 200°C, 210°C, and 220°C. It shows that the melting temperature affects the tensile strength of the recycled HDPE and liquid asphalt mixture with a composition of 85:15. A temperature of 200°C produces the highest maximum stress of 6.5 MPa with a strain of around 0.03%, indicating the best mechanical performance. At 210°C, the stress decreases to approximately 5.7 MPa, while at 220°C the stress value is lower and the graph tends to flatten out. This indicates that 200°C is the most optimal temperature for producing a material that is both strong and sufficiently elastic at this composition.

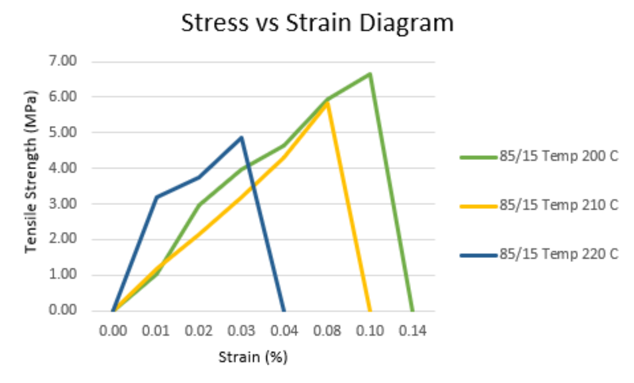

Figure 5. Stress-strain graph of 85/15 composition

Figure 6 shows a graph of the relationship between tensile stress and strain in specimens composed of 90% recycled HDPE plastic and 10% liquid asphalt, tested at melting temperatures of 200°C, 210°C, and 220°C.

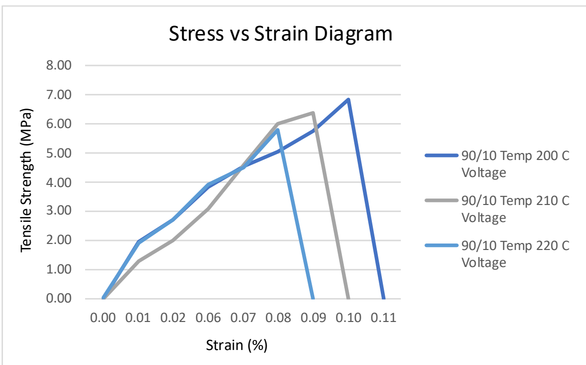

Figure 6. Stress-strain graph of 90/10 composition

It shows that the melting temperature affects the tensile strength of the recycled HDPE and liquid asphalt mixture with a composition of 90:10. A temperature of 200°C produces the highest maximum stress of 6.85 MPa with a strain of approximately 0.11%, indicating the best performance. At 210°C, the stress decreases to approximately

6.4 MPa, and the graph drops sharply after the peak. At 220°C, the stress is lower, and the curve tends to flatten out. Therefore, 200°C is the most optimal condition for this composition.

To determine the extent of the influence of melting temperature, the composition of the HDPE plastic and liquid asphalt mixture, and the interaction between the two on the tensile strength of the material, a two-way analysis of variance (ANOVA) was performed. The ANOVA test results are presented in Table 4.

Table 4. Results of Two-Way ANOVA Analysis

Analysis of Variance					
Source	Df	Adj SS	Adj MS	F-Value	P-Value
temperature (°C)	2	3.1502	1.5751	5.61	0.013
Composition HDPE:Asphalt	2	12.6777	6.3389	22.58	0.000
temperature (°C)*Composition HDPE:Asphalt	4	0.7275	0.1819	0.65	0.636
Eror	18	5.0522	0.2807		
Total	26	21.6076			

Based on the ANOVA results, it is known that the plastic:asphalt composition has a very significant effect on the mechanical properties of the material with a p-value of 0.000, while the melting temperature also has an effect but at a lower level of significance, namely with a p-value of 0.013. Although both are below the significance threshold of 0.05, the smaller p-value indicates that the plastic:asphalt composition has a more dominant influence on the results compared to the melting temperature. Meanwhile, the interaction between the two factors resulted in a p-value of 0.636, which is not significant. This indicates that the influence of each factor on the material properties is independent, or does not affect each other. Additionally, the interaction graph between the melting temperature variable and the HDPE plastic:liquid asphalt mixture composition on the material's maximum tensile strength value is shown in Figure 7.

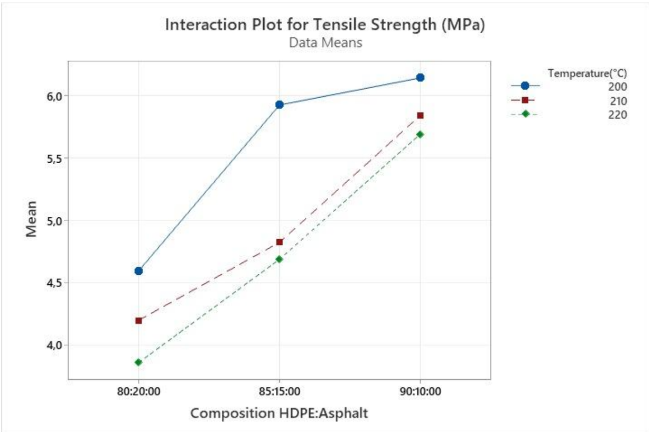

Figure 7. Interaction plot

Based on the interaction plot graph, it can be concluded that the higher the plastic composition in the plastic:asphalt mixture, the maximum tensile strength increases consistently across all melting temperature variations. This indicates that the plastic:asphalt composition has an effect on improving the mechanical properties of the material. Meanwhile, for the melting temperature factor, it is observed that 200°C produces the highest tensile strength, followed by 210°C, and the lowest at 220°C. This pattern indicates that an increase in melting temperature actually reduces the material's tensile strength, likely due to thermal degradation or a decrease in the integrity of inter-component bonds at extremely high temperatures. The three lines do not intersect, confirming that there is no significant interaction between composition and temperature, and each factor can be analyzed independently, as also demonstrated by the ANOVA results.

Figure 8 shows the relationship between variations in melting temperature and the maximum tensile strength of specimens made from a mixture of liquid asphalt and recycled HDPE plastic. There is a decrease in tensile strength as the melting temperature increases. A melting temperature of 200°C produces the highest average tensile strength, which is around 5.57 MPa. However, when the temperature is increased to 210°C and 220°C, the tensile strength decreases to around 4.95 MPa and 4.75 MPa, respectively. This pattern indicates that mixing at too high a temperature tends to reduce tensile strength, due to thermal degradation of the material. Thus, a melting temperature of 200°C can be considered the optimal condition for producing the best tensile mechanical properties in the material.

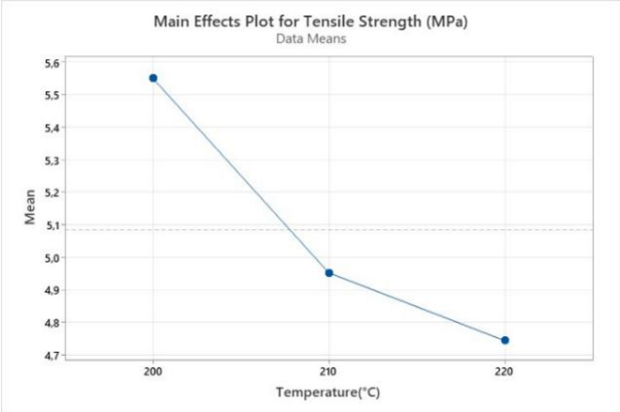

Figure 8. Main effects plot

Figure 9 illustrates the effect of varying the composition of recycled HDPE plastic mixed with liquid asphalt on maximum tensile strength.

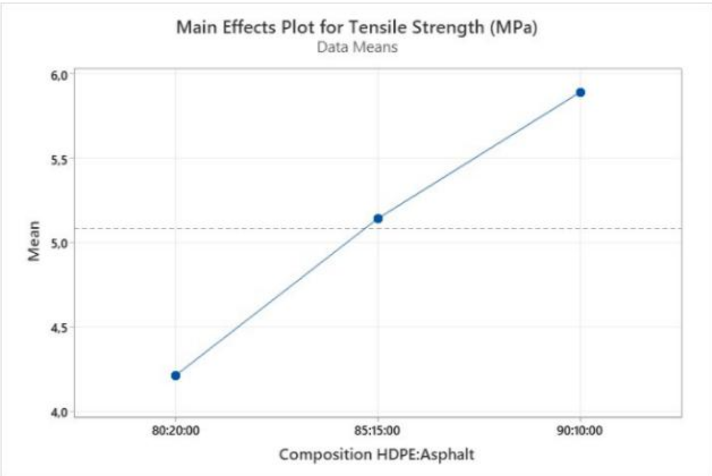

Figure 9. Main effect plot tensile strength

It can be seen that the higher the percentage of plastic in the mixture, the greater the tensile strength produced. At a composition of 80:20 (plastic:asphalt), the average tensile strength obtained is around 4.2 MPa. This value increases significantly to approximately 5.2 MPa at a composition of 85:15, and reaches a maximum value of approximately 5.9 MPa at a composition of 90:10. These results indicate that increasing the proportion of plastic in the mixture can enhance the mechanical properties of the material, particularly tensile strength, as HDPE plastic tends to provide better tensile strength compared to liquid asphalt.

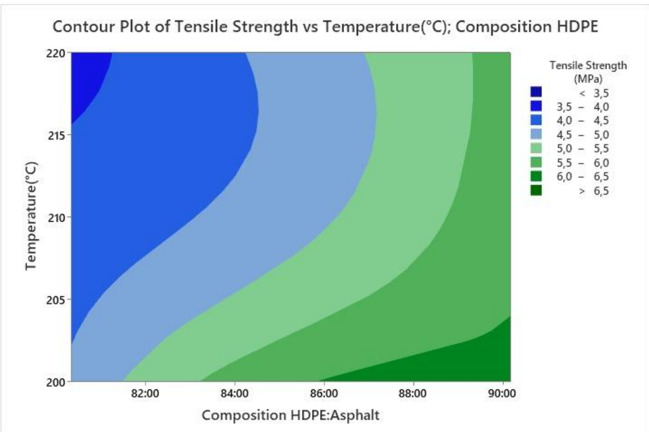

Figure 10. Contour plot

Figure 10 presents a contour plot illustrating the influence of the interaction between melting temperature and plastic:asphalt composition on the maximum tensile strength (MPa). From the color gradient pattern on the graph, it can be seen that the highest tensile strength is achieved in areas with high plastic composition (close to 90:10) and lower melting temperatures (around 200°C). The dark green color indicates zones with tensile strength greater than 6.0 MPa, which are consistently found in that area. Conversely, in regions with high temperatures (approaching 220°C) and low plastic content (around 80:20), the blue color dominates, indicating tensile strength below 4.0 MPa. When compared to pure asphalt, which typically has tensile strength values in the range of 1–2 MPa as reported by [14], the tensile strength of the HDPE–asphalt composites in this study is significantly higher. These results indicate that there is a significant interaction between the two independent variables in determining the mechanical properties of the material. Excessively high melting temperatures tend to reduce tensile strength, especially if not balanced by adequate plastic content. Therefore, the optimal combination for achieving the best tensile strength is at low temperatures and high plastic composition.

4. CONCLUSION

The following conclusions can be drawn from the research conducted:

1) The melting temperature of HDPE has a significant effect on the tensile strength of the material. A temperature of 200°C produces the highest tensile strength value, while at a temperature of 220°C the tensile strength value decreases. This indicates that increasing the melting temperature above 210°C causes a decrease in tensile strength, likely due to thermal degradation of the material.
2) The composition of the mixture between recycled HDPE plastic and liquid asphalt also affects the tensile strength value. A composition of 90% HDPE and 10% liquid asphalt produces the highest tensile strength compared to other compositions. This means that the higher the percentage of HDPE in the mixture, the greater the tensile strength produced.
3) The best combination in this study was found in the 90:10 (HDPE:asphalt) composition at a melting temperature of 200°C, yielding an average tensile strength value of 6.14 MPa. Meanwhile, the lowest combination was found in the 80:20 composition at a temperature of 220 °C, with an average value of 3.86 MPa.

5. ACKNOWLEDGEMENT

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